European Journal of Operational Research 203 (2010) 370–379

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Production, Manufacturing and Logistics

Managing new and differentiated remanufactured products

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ARTICLE INFO

Article history:
Received 5 October 2008
Accepted 10 August 2009
Available online 15 August 2009

Keywords:
Remanufacturing
Differentiated products
Monopoly
Product portfolio
Multi-period horizon

ABSTRACT

We study a firm that makes new products in the first period and uses returned cores to make remanufactured products (along with new products) in future periods. The remanufactured product is differentiated from the new product, so the firm needs to choose differentiated prices. We analyze the monopoly environment in two-period, multi-period (three, four and five) and infinite planning horizons, and characterize the optimal remanufacturing and pricing strategy for the firm. In the process, we identify remanufacturing savings thresholds that determine the production and pricing strategy for the firm. Among other results, we find—counter to intuition—that in a finite-horizon, multi-period setting, the optimal policy is not necessarily monotone in remanufacturing savings.

Published by Elsevier B.V.

1. Introduction

Remanufacturing is a process in which used products are disassembled, and their parts are repaired and used in the production of new products. Remanufactured products often serve entry-level customers that are attracted by the brand, but do not wish to pay the price of a new product—as with used cars. A successful remanufacturing operation often adopts high quality standards that allow it to offer products that enhance brand equity and keep customers loyal. Often, the company expands its market coverage by offering remanufactured products at a low price, side-by-side with the new products. A well-designed product line that includes remanufactured and new products may increase market share while sustaining a high profit margin. An organization will find it most economical to remanufacture equipment that satisfies the following conditions: it is owned in large quantities (economies-of-scale requirement); all units have the same configuration (learning curve requirement); all units can be brought to current state of technology (non-obsolescence requirement). The US Department of Defense consistently remanufactures most of its valuable assets (propulsion units, vehicles, radar systems) precisely because they satisfy these conditions. In fact, remanufacturing has been recognized in many government reports as an economical way to maintain all fleets at desirable levels (US DoD, 2005).

This study is concerned with the remanufacturing operation from the supplier's viewpoint. We analyze a monopoly model in which the remanufactured and the original products are clearly distinguishable. We develop models for several planning horizons, such that the manufacturer produces just the new product in the first period, but has the option of making new and remanufactured products in subsequent periods. Pricing decisions impact the dynamics across periods in such cases. For example, if the price is high in the first period, profits in the first period might increase; but, the number of reusable products available in the second period decreases, thereby reducing second period profit potential. However, if the price is low in the first period, initial profits might decrease, but the firm has better remanufacturing opportunity in future periods.

We start by deriving the optimal quantities and prices for such an operation, and characterize the optimal conditions for a monopolist that offers both product types, unconstrained by the availability of cores, characterizing the strategic regions of operation. Then, we analyze models constrained by core availability. We introduce the infinite-horizon model, assuming steady behavior in the second period and beyond. Finally, we introduce the multi-period problem with limited planning horizon and discuss the initialization and the end-gaming behavior. We provide analytical insights for all cases.

The rest of the paper is organized as follows: In Section 2, we discuss the related literature and our contributions. In Section 3, we present our model and results. In Section 3.1, we present the infinite-horizon, and in Section 3.2, we analyze the two-period planning horizon. In Section 3.3, we study the multi-period planning horizon—focusing in particular on three-, four- and five-period horizons. We conclude in Section 4.

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0377-2217/$ - see front matter Published by Elsevier B.V.
doi:10.1016/j.ejor.2009.08.007

2. Related research

Buy-backs, trade-ins and leasing schemes provide market benefits to the manufacturer that are not trivial. These benefits have raised the question: what is the optimal sales strategy of a company making a durable product to improve its potential profits? How should buy-back and leases be considered? In an early study, Levinthal and Purohit (1989) provide a two-period model that describes a monopolist company selling a durable product for which it may subsequently introduce an improved version. In a situation like this, the customers will expect a forthcoming product, and as a result, will lower the price they are willing to pay for the current product due to its expected loss in value. A buy-back policy is found to be more profitable for large improvements, whereas the policy to phase-out sales of the old product is optimal for modest levels of improvement. Purohit (1992) examines the situation in which technology changes rapidly, and the new versions of a product make earlier versions obsolete. However, when the products are durable, there is the possibility of secondary markets for used products as well as for outdated products. These examples can be found everywhere today—particularly in computer and high-tech industries. Purohit develops a model to explore the relationship between primary and secondary markets for automobiles. The results suggest that the depreciation of old models is influenced strongly by the types of changes in new models. In related research, Hendel and Lizzeri (1999) propose a model in which consumers have heterogeneous valuations for quality; thus, the used-good markets play an allocative role to address the interference introduced by the first market on the secondary market of a monopolist company. Market-related issues in remanufacturing are related to discussions of other secondary distribution/segmentation channels, as found in Purohit and Staelin (1994). They provide different policies to increase the total manufacturer's profit in a two-period model that compares buy-back and lease schemes.

There is also great interest in supply-chain coordination to maximize multi-period profits. Moorthy and Png (1992), Kim and Chhajed (2002), and Krishnan and Zhu (2006) develop quality-based models for new product development with multiple market segments under different marketing and manufacturing considerations. Desai et al. (2002) study the coordination problem between manufacturer and retailer of durable products which arises from the potential competition from a secondary market in future periods. In another two-period model, Desai et al. (2007) evaluate how a manufacturer decides first period production level under stochastic demand, with excess production carry-over to second period.

The literature on the economics of remanufacturing has seen important contributions in the study of supply-chain coordination (Corbett and Savaskan, 2002; Savaskan et al., 2004; Savaskan and Van Wassenhove, 2006), collection and leasing (Guide et al., 2003; Ray et al., 2005; Heese et al., 2005; Qu and Williams, 2008; Liang et al., 2009). The research in this field is rapidly evolving, as witnessed by the many special issues and technical books (Corbett and Kleindorfer, 2001; Dekker et al., 2004; Fleischmann et al., 2004; Flapper et al., 2005). For an extensive review of the reverse logistics literature, an interested reader may refer to Fleischmann et al. (1997) and Guide et al. (2000).

Debo et al. (2005) develop a multi-period, infinite-horizon model to price remanufactured goods and to determine the product technology *a priori* to maximize the profitability of the market segmentation. Majumder and Groenevelt (2001) describe a two-period model where the original-equipment manufacturer (OEM) may choose to remanufacture in the second period or not. The reverse logistics process is based on the "shell allocation mechanism" observed in the respective market. Four of these mechanisms are considered: whether one or the other player (the OEM and the independent operator) can or cannot use the cores that are not utilized by the other company. Ferrer and Swaminathan (2006) expand on the above model and characterize the optimal strategies (production quantities and prices) in monopoly and duopoly environments for two-period, multi-period and infinite-horizon settings. One of the main findings is that if the profit margin in remanufacturing reaches defined threshold, then the firm reduces the price in the first period in order to sell more units and increase the number of available cores in the following periods. They also prove that, if the savings of one party from remanufacturing is high enough compared other parties, the original organization remanufactures all available cores that it collects. Furthermore, they show that for most practical environments, the optimal strategies obtained for the two-period problem are quite similar to the results of multi-period problems. Ferguson and Toktay (2006) formulate a two-period model to examine the recovery strategy of the OEM in the face of a competitor. In the first part of the paper, they show the cannibalization effect of the remanufactured products on the original products. In the second part, they present two entry-deterrent strategies that the OEM may follow in order to keep the remanufacturer away from the market. The results show that the OEM may remanufacture (after collecting the cores) or collect the cores, but not remanufacture (preemptive collection) based on factors such as collection or remanufacturing cost.

It is worth mentioning the increasing literature on closed-loop supply chain that is generally concerned with managing the inventory of used cores to meet the needs of the remanufacturing process, either in quantities, quality or both. Recent examples include Choi et al. (2007), Konstantaras and Papachristos (2007), Teunter et al. (2008), Visich et al. (2007), Zikopoulos and Tagaras (2007) and Zikopoulos and Tagaras (2008). The tutorial by Souza summarizes some of the key components of these models (Souza, 2008).

In most of the above literature, it is assumed that remanufactured and original products are not distinguishable, and in those that study differentiated products, the analysis is restricted to two periods. However, the remanufactured products are often offered as an alternative to the original products with lower price and/or quality. For example, there are a number of industries such as computer systems, auto components and office equipment in which the reconditioned product is priced lower than original products in order to capture the demand in different markets (Ferrer, 1997; Ayres et al., 1997). Robotis et al. (2005) analyze the case of a reseller who procures cores which have an older technology and then either resells a fraction of these cores in "as is" condition (in a developing market) or remanufactures the cores and then sells them at a higher price. They show that the number of collected cores decreases when the reseller utilizes remanufacturing and, depending on the cost structure, it might be always more profitable to remanufacture the collected cores.

Incorporating the distinguished (or quality differentiated) nature of remanufactured products complicates the problem substantially, since there is one more lever (related to price differentiation) that needs to be considered. In this paper, we study a firm that makes new products in the first period and uses returned cores to make remanufactured products (along with new products) in future periods. The remanufactured product is differentiated from the new product, so the firm needs to choose differentiated prices. We present the multi-period (three, four and five) planning horizons and show their relationship with past analysis with the two-period and the infinite planning horizon. In all cases, we characterize the remanufacturing savings thresholds that define the optimal remanufacturing quantity and price strategy for the firm. Among other results, we find (counter to intuition) that in a